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Space Correlation Based Joint Admission Control in Cognitive MIMO Systems

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Abstract

A joint transmit-receive admission control strategy based on spatial information in cognitive MIMO systems is proposed. By exploiting space correlation features between cognitive transmission and interference from cognitive base station (CBS) to primary user (PU) as well as from primary base station (PBS) to cognitive user (CU), appropriate primary system and its channel are selected. Then spectrum sharing is carried out employing signal subspace orthogonal projection. Simulation results show that the proposed scheme could achieve near-optimal system throughput performance with reduced complexity.

Keywords: Cognitive radio; MIMO; Admission control; precoding; Orthogonal projection

1. Introduction

With rapid development of wireless communications, the contradiction between physical scarcity of usable frequencies and underutilization of spectrum resources becomes more and more serious. Cognitive radio (CR) that adapts to electromagnetic environment and accomplishes dynamic spectrum access originates as a possible solution [1-2]. Basically there are two major issues in the study of CR, one is spectrum sensing, the other is admission control for cognitive user. In some recent works, multi-input multi-output (MIMO) techniques are introduced into CR and novel spectrum sensing, sharing methods and joint resource management schemes are designed [3-5]. Among these works, [3] proposes a multi-antenna based spectrum sensing method, [4] proposes a multi-antenna framework for spectrum reuse in

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cognitive cellular systems, in [5] a space division multiplexing based spectrum sharing scheme for CR MIMO is designed and antenna requirements for cognitive are given.

The above works [4-5] take single authorized system into account, however multiple systems cover the same area is usual in practical use. Thus on the premise that the spatial features of cognitive and primary transmission as well as inter-system interference channels are available, a joint transmit-receive admission control strategy in cognitive MIMO systems is proposed in this paper. By exploiting spatial correlation features between cognitive transmission and interference from CBS to PU as well as from PBS to CU, near-optimal throughput performance with reduced complexity is achieved.

Notation: Bold-face letters are used to denote matrices and vectors. Let $\mathbf{X}^H$ and $\mathrm{rank}(\mathbf{X})$ denote the Hermitian and rank of matrix $\mathbf{X}$. $|\cdot|$ and $\|\cdot\|$ indicate the scalar norm and the Euclidean norm, respectively. We define $\langle \mathbf{a}, \mathbf{b} \rangle$ as the inner product of vector $\mathbf{a}$ and $\mathbf{b}$.

2. System Model

Consider downlink transmission in an area covered by *K* authorized systems and one cognitive system corporately. Each primary system consists of one PBS and multiple PUs. For simplicity, cognitive system contains only one CU. The system model is depicted in Fig. 1 where $K = 2$.

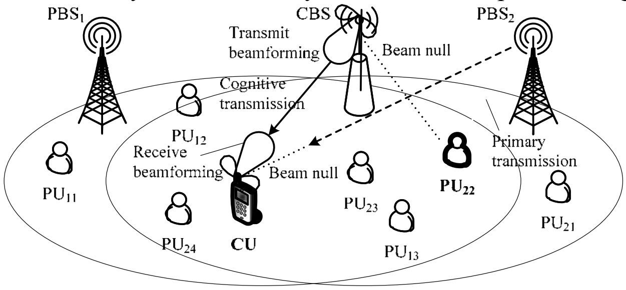

Fig. 1. System model

The number of antennas at PBS$_k$ (PBS in primary system *k*, $k = 1, \cdots, K$) and CBS are denoted as M_{tk}^p and M_t^c, for PU belonging to system *k* and CU are M_{rk}^p and M_r^c, respectively. The authorized spectrum for system *k* consists of L_k channels, each with bandwidth *B*. The channels are frequency non-selective fading. For convenience, we assume antenna configuration and number of authorized frequency channels of all primary systems are identical. Then we have $M_{tk}^p = M_t^p$, $M_{rk}^p = M_r^p$ and $L_k = L$. Multiple PUs dynamically share the authorized channels. Both PBS and CBS transmit to their subscribers in a time division duplex (TDD) manner. Thus channel reciprocity holds.

In one slot, channel state information (CSI) between PBS$_k$ and PU occupying channel l in primary system *k* (PU$_{lk}$) is denoted as $\mathbf{H}_{lk}^p$. CSI between CBS and CU who shares channel *l* in system *k* with the primary is $\mathbf{H}_{lk}^c$, CSI between CBS and PU$_{lk}$ is $\mathbf{H}_{lk}^{cp}$, and CSI between PBS$_k$ and CU which coexists with the primary in channel *l* of system *k* is $\mathbf{H}_{lk}^{pc}$. The time index is omitted for simplicity. We assume channel information is available for both primary and cognitive. All the links dedicated to channel information delivery are reliable. The channels are quasi-static [6-7]. Moreover, channel states between PBS$_k$ and CU as well as CBS and CU mainly depend on the spatial arrangement of devices and the distribution of scatters in communication environment. Thus $\mathbf{H}_{1k}^{pc} = \cdots = \mathbf{H}_{Lk}^{pc} = \mathbf{H}_k^{pc}$ and $\mathbf{H}_{11}^c = \cdots = \mathbf{H}_{LK}^c = \mathbf{H}^c$.

3. Joint Transmit-Receive Admission Control

The following discussion is in the coexistence scenario where all the authorized frequency channels are occupied by the primary. Thus the proposed scheme is a complement for conventional CR.

3.1. Basic Signal Processing

Transmit power of PBS_k and CBS are E_k^p and E^c, let $E_k^p = E^p = E^c$. Assume beamforming (BF) is adopted in both primary and secondary transmissions. The transmit symbols from PBS_k to PU_{lk} is denoted as x_{lk}^p. Similarly, symbols from CBS to CU is x^c. At the transmitter end, use $\mathbf{p}_{lk}^p$ to denote the precoding vector employed in the primary transmission from PBS_k to PU_{lk}. $\mathbf{p}_{lk}^c$ is the precoding vector at CBS which transmits to CU via sharing channel *l* of authorized system *k* with the primary. At the receiver end, $\mathbf{f}_{lk}^p$ and $\mathbf{f}_{lk}^c$ are used to denote the receive filters at PU_{lk} and CU, respectively.

Apply singular value decomposition (SVD) to $\mathbf{H}_{lk}^p$, $\mathbf{H}_{lk}^p = \mathbf{U}_{lk}^p \mathbf{\Lambda}_{lk}^p (\mathbf{V}_{lk}^p)^H$. $\lambda_{lk,1}^p$ represents the maximum singular value of $\mathbf{H}_{lk}^p$. PBS_k adopts $\mathbf{v}_{lk,1}^p$ to implement transmit preprocessing. PU_{lk} uses the Hermitian of $\mathbf{u}_{lk,1}^p$ to carry out receive filtering. Then we have $\mathbf{p}_{lk}^p = \mathbf{v}_{lk,1}^p$ and $\mathbf{f}_{lk}^p = \mathbf{u}_{lk,1}^p$. Both $\mathbf{v}_{lk,1}^p$ and $\mathbf{u}_{lk,1}^p$ are corresponding to $\lambda_{lk,1}^p$. The estimated signal at PU_{lk} is

$$\overline{y}_{lk}^p = (\mathbf{u}_{lk,1}^p)^H \mathbf{H}_{lk}^p \mathbf{v}_{lk,1}^p x_{lk}^p + (\mathbf{u}_{lk,1}^p)^H \mathbf{H}_{lk}^{cp} \mathbf{p}_{lk}^c x^c + (\mathbf{u}_{lk,1}^p)^H \mathbf{n} = \lambda_{lk,1}^p x_{lk}^p + (\mathbf{u}_{lk,1}^p)^H \mathbf{H}_{lk}^{cp} \mathbf{p}_{lk}^c x^c + (\mathbf{u}_{lk,1}^p)^H \mathbf{n} \tag{1}$$

$\mathbf{n}$ is additive white Gaussian noise vector, whose element has variance σ_n^2. $\mathbf{p}_{lk}^c$ should be designed such that the interference from CBS $(\mathbf{u}_{lk,1}^p)^H \mathbf{H}_{lk}^{cp} \mathbf{p}_{lk}^c = 0$.

When there is no idle spectrum available, cognitive user carries out spectrum sharing with the primary. In one slot the received signal of CU who is sharing the frequency channel *l* within authorized system *k* is

$$\mathbf{y}_{lk}^c = \mathbf{H}^c \mathbf{p}_{lk}^c x^c + \mathbf{H}_k^{pc} \mathbf{v}_{lk,1}^p x_{lk}^p + \mathbf{n} \tag{2}$$

The second term in the RHS of (2) is the interference from PBS_k. The estimated signal at CU is

$$\overline{y}_{lk}^c = (\mathbf{f}_{lk}^c)^H \mathbf{H}^c \mathbf{p}_{lk}^c x^c + (\mathbf{f}_{lk}^c)^H \mathbf{H}_k^{pc} \mathbf{v}_{lk,1}^p x_{lk}^p + (\mathbf{f}_{lk}^c)^H \mathbf{n} \tag{3}$$

$\mathbf{f}_{lk}^c$ should be designed such that $(\mathbf{f}_{lk}^c)^H \mathbf{H}_k^{pc} \mathbf{v}_{lk,1}^p = 0$. Apply SVD to $\mathbf{H}^c$, $\mathbf{H}^c = \mathbf{U}^c \mathbf{\Lambda}^c (\mathbf{V}^c)^H$. $\mathbf{p}_{lk}^c$ and $\mathbf{f}_{lk}^c$ are obtained by proper processing of $\mathbf{u}_1^c$ and $\mathbf{v}_1^c$, respectively. The algorithms are given as follows.

CBS precoder design:

(1) Construct matrix $\mathbf{T}_{lk}^c = [\mathbf{v}_{lk,1}^{cp}, \cdots, \mathbf{v}_{lk,\mathrm{rank}(\mathbf{H}_{lk}^{cp})}^{cp}, \mathbf{v}_2^c, \cdots, \mathbf{v}_{\mathrm{rank}(\mathbf{H}^c)}^c]$. Apply the Gram-Schmidt orthogonalization to $\mathbf{T}_{lk}^c$, $\overline{\mathbf{T}}_{lk}^c = [\overline{\mathbf{t}}_{lk,1}^{cp}, \cdots, \overline{\mathbf{t}}_{lk,\mathrm{rank}(\mathbf{H}_l^{cp})}^{cp}, \overline{\mathbf{t}}_2^c, \cdots, \overline{\mathbf{t}}_{\mathrm{rank}(\mathbf{H}^c)}^c]$.

(2) Project $\mathbf{v}_1^c$ onto the orthogonal subspace spanned by $\overline{\mathbf{T}}_{lk}^c$. $\tilde{\mathbf{v}}_{lk}^c = \mathbf{v}_1^c - \sum_{m=1}^{\mathrm{rank}(\mathbf{H}_{lk}^{cp})} \left[\overline{\mathbf{t}}_{lk,m}^{cp}\right]^H \mathbf{v}_1^c \overline{\mathbf{t}}_{lk,m}^{cp} - \sum_{n=2}^{\mathrm{rank}(\mathbf{H}^c)} \left[\overline{\mathbf{t}}_n^c\right]^H \mathbf{v}_1^c \overline{\mathbf{t}}_n^c$.

(3) Normalize $\tilde{\mathbf{v}}_{lk}^c$, we have the precoding vector $\mathbf{p}_{lk}^c = \tilde{\mathbf{v}}_{lk}^c / \| \tilde{\mathbf{v}}_{lk}^c \|$.

Apply SVD to $\mathbf{H}_k^{pc}$, $\mathbf{H}_k^{pc} = \mathbf{U}_k^{pc} \mathbf{\Lambda}_k^{pc} (\mathbf{V}_k^{pc})^H$. CU Filter design is

(1) Construct matrix $\mathbf{R}_k^c = \mathbf{U}_k^{pc} = [\mathbf{u}_{k,1}^{pc}, \cdots, \mathbf{u}_{k,\mathrm{rank}(\mathbf{H}_k^{pc})}^{pc}]$. As the vectors constructing $\mathbf{U}_k^{pc}$ form an orthonormal basis, introduce $\overline{\mathbf{R}}_k^c = \mathbf{R}_k^c$.

(2) Project $\mathbf{u}_{k,1}^c$ onto the orthogonal subspace spanned by $\overline{\mathbf{R}}_k^c$. $\tilde{\mathbf{u}}_{k,1}^c = \mathbf{u}_{k,1}^c - \sum_{m=1}^{\mathrm{rank}(\mathbf{H}_k^{pc})} \left[\overline{\mathbf{u}}_{k,m}^{pc}\right]^H \mathbf{u}_{k,1}^c \overline{\mathbf{u}}_{k,m}^{pc}$.

(3) Normalize $\tilde{\mathbf{u}}_{k,1}^c$, we have the filtering vector $\mathbf{f}_{lk}^c = \tilde{\mathbf{u}}_{k,1}^c / \| \tilde{\mathbf{u}}_{k,1}^c \|$.

The achievable rate of cognitive transmission is given by (4).

$$R_{lk}^c = \log_2 \left(1 + E^c (\lambda_1^c)^2 \,|\, \chi_{lk} \,|^2 / \sigma_n^2\right) \tag{4}$$

$\chi_{lk} = (\mathbf{f}_{lk}^c)^H \mathbf{u}_1^c (\mathbf{v}_1^c)^H \mathbf{p}_{lk}^c$. λ_1^c is the maximum singular value of $\mathbf{H}^c$. Note that $\left|\left\langle \mathbf{v}_1^c, \mathbf{p}_{lk}^c \right\rangle\right|^2 < 1$ and $\left|\left\langle \mathbf{f}_{lk}^c, \mathbf{u}_1^c \right\rangle\right|^2 < 1$. The expected user signal from CBS to CU is deteriorated.

3.2. Transmit-Receive Joint Admission Control

According to Section 3.1, the selection diversity of primary system and its channel is achieved. A joint admission control strategy is as follows.

(1) CU calculates spatial correlation between cognitive transmission and interference from PBS$_k$ to CU according to channel states $\mathbf{H}^c$ and $\mathbf{H}_k^{pc}$, where $k \in \{1,\cdots,K\}$. $Cor_k^{CU} = \sum_{n=1}^{\mathrm{rank}(\mathbf{H}_k^{pc})} \left|\left\langle \mathbf{u}_1^c, \mathbf{u}_{k,n}^{pc} \right\rangle\right|$.

(2) CU determines the index of target primary system. $k_{tgt} = \arg \min_{k\in\{1,\cdots,K\}} (Cor_k^{CU})$.

(3) CBS calculates $\overline{\mathbf{T}}_{lk_{tgt}}^c$ and the spatial correlation according to channel states $\mathbf{H}_{lk_{tgt}}^{cp}$ and $\mathbf{H}^c$, where $l \in \{1,\cdots,L\}$. $Cor_{lk_{tgt}}^{CBS} = \sum_{n=1}^{\mathrm{rank}(\mathbf{H}_{lk_{tgt}}^{cp})} \left|\left\langle \mathbf{v}_1^c, \overline{\mathbf{t}}_{lk_{tgt},n}^{cp} \right\rangle\right| + \sum_{m\neq 1}^{\mathrm{rank}(\mathbf{H}^c)} \left|\left\langle \mathbf{v}_1^c, \overline{\mathbf{t}}_m^c \right\rangle\right|$.

(4) CBS determines the index of target frequency channel within primary system k_{tgt} . $l_{tgt} = \arg \min_{l\in\{1,\cdots,L\}} (Cor_{lk_{tgt}}^{CBS})$.

(5) Cognitive transmission shares channel l_{tgt} within authorized system k_{tgt} by following signal processing procedures in Section 3.1.

With the above strategy, admission control is implemented at CBS and CU jointly. Spatial features between CBS and different PU as well as different PBS and CU are fully exploited. In order to make comparison, a CBS based admission control strategy and exhaustive searching are also used. For simplicity the procedures of exhaustive searching are not elaborated. The CBS based admission control is as follows.

(1) CBS computes $\overline{\mathbf{T}}_{lk}^c$ in terms of the first step of CBS precoder design and channel states $\mathbf{H}_{lk}^{cp}$ and $\mathbf{H}^c$, where $k \in \{1,\cdots,K\}$ and $l \in \{1,\cdots,L\}$. Then calculate spatial correlation. $Cor_{lk}^{CBS} = \sum_{n=1}^{\mathrm{rank}(\mathbf{H}_{lk}^{cp})} \left|\left\langle \mathbf{v}_1^c, \overline{\mathbf{t}}_{lk,n}^{cp} \right\rangle\right| + \sum_{m\neq 1}^{\mathrm{rank}(\mathbf{H}^c)} \left|\left\langle \mathbf{v}_1^c, \overline{\mathbf{t}}_m^c \right\rangle\right|$.

(2) Determine the indices of target primary system and its frequency channel. $(l_{tgt}, k_{tgt}) = \arg \min_{l\in\{1,\cdots,L\},k\in\{1,\cdots,K\}} (Cor_{lk}^{CBS})$.

(3) Cognitive transmission shares channel l_{tgt} within primary system k_{tgt} by following signal processing procedures in Section 3.1.

From the above description it can be seen that with joint admission control, CBS carries out channel selection within the target primary system reported by CU. The complexity could be notably reduced compared with exhaustive searching. Although the partial utilization of context information would result in some throughput loss, the amount is marginal as will be demonstrated in the simulation part.

4. Simulation Results

In this section, we use simulation results to demonstrate the advantages of proposed strategy. We adopt $M_t^p = M_r^p = 2$, $M_t^c = 5$ and $M_r^c = 3$ [5]. Simulation results under different antenna configurations are not shown, however the same conclusion can be drawn. We adopt BF for both primary and cognitive transmission.

In Fig. 2(a) throughputs of three strategies under K=4, $L \in \{8,20\}$ and different SNR are plotted. With same L, CBS control gives the worst performance. Joint admission control is close to exhaustive searching which achieves the optimal throughput performance. Both exceed CBS selection notably. As multiuser diversity gain increases with L, provided with the same method large L leads to high throughput.

Fig. 2(b) plots the throughputs of three strategies under SNR=6dB, $L \in \{8,20\}$ and different K. As shown in the figure, with increasing K throughputs of three strategies enlarge due to selection diversity gain brought by multiple primary systems. When K is large enough throughputs go saturate. when $K = 1$ the selection is within the only authorized system, thus three schemes output the same results.

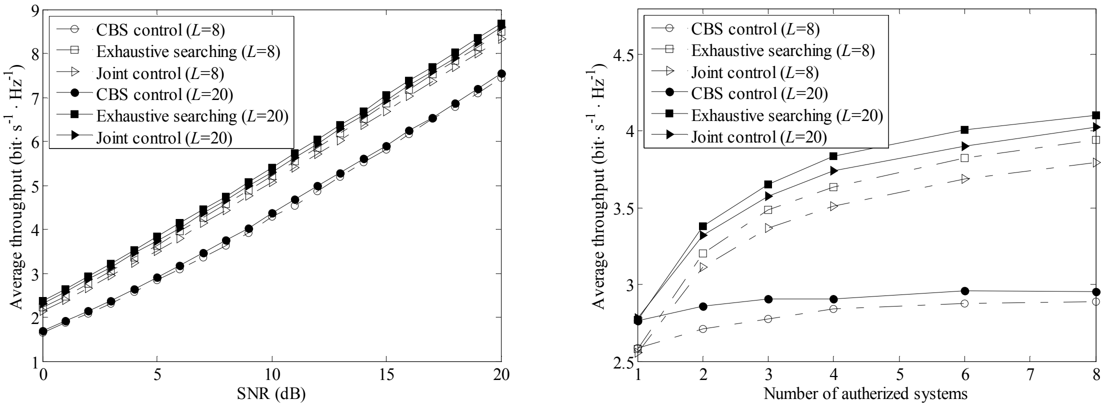

Fig. 2. (a) Average throughput under K=4 and $L \in \{8, 20\}$; (b) Average throughput under SNR=6dB and $L \in \{8, 20\}$.

5. Conclusions

In this paper a joint transmit-receive admission control strategy for cognitive MIMO systems is proposed. By exploiting spatial correlation features between cognitive transmission and inter-system interference, appropriate primary system and its channel are selected under the condition that no idle spectrum resource is available. The method is a good complement for conventional CR. Compared with the CBS based admission control and exhaustive searching, the proposed scheme achieves good tradeoff between throughput performance and system complexity.

References

[1] Mitola J. Cognitive radio for flexible mobile multimedia communication. *IEEE Int. Workshop Mobile Multimedia Commun. (MoMuC)* 1999, p. 3-10.

[2] Devroye N, Vu M, Tarokh V. Cognitive Radio Networks. *IEEE Sig. Process. Mag.* 2008, vol. 25, no. 6, p. 12-23.

[3] Zhang Rui, Lim Teng, Liang Ying-Chang, Zeng Yonghong. Multi-Antenna Based Spectrum Sensing for Cognitive Radios: A GLRT Approach. *IEEE Trans. Commun.* 2010, vol. 58, no. 1, p. 84-88.

[4] Bakr O, Johnson M, Wild B, Mudumbai R, Ramchandranet K. A multi-antenna framework for spectrum reuse based on primary-secondary cooperation. *IEEE Symp. on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)* 2008, p. 1-5.

[5] Li Z, Liu Q, Zhao L. Space Division Multiplexing Aided Opportunistic Spectrum Access for Cognitive Radio Networks. *IEEE Int. Conf. on Advanced Inf. Net. and App.(AINA)* 2011, p. 1-6.

[6] Jitvanichphaibool K, Liang Ying-Chang, Zhang Rui. Beamforming and Power Control for Multi-Antenna Cognitive Two-Way Relaying. *IEEE Wireless Commun. and Net. Conf. (WCNC)* 2009, p. 1-6.

[7] Hamdi K, Zhang Wei, Letaief K. Opportunistic spectrum sharing in cognitive MIMO wireless networks. *IEEE Trans. Wireless Commun.* 2009, vol. 8, no. 8, p. 4098-4107.